

Redetermination of the Wave-Lengths

OF THE

ARC AND THE SPARK LINES OF TITANIUM, MANGANESE,
AND VANADIUM; THE EFFECT OF CAPACITY
AND SELF-INDUCTION ON THE WAVE-
LENGTHS OF THE SPARK LINES

BY

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DISSERTATION

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REDETERMINATION OF THE WAVE-LENGTHS OF THE ARC AND THE SPARK LINES OF TITANIUM, MAN- GANESE, AND VANADIUM; THE EFFECT OF CAPA- CITY AND SELF-INDUCTION ON THE WAVE- LENGTHS OF THE SPARK LINES

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I. WAVE-LENGTHS OF ARC AND SPARK LINES

INTRODUCTION

The importance of accurate determinations of the wave-lengths is of course fully recognized, and so this undertaking needs no apology. The history of such work is parallel with that of spectroscopic instruments. With each improvement of instruments greater accuracy has been attained, and finally such accuracy as to cause perception of the difference between the solar and the arc standards of wave-length.

As the iron arc standards have now been generally accepted, the necessity of redetermining the wave-lengths formerly based on solar standards is apparent. This fact, together with the opportunity afforded by the accessibility to the most excellent 21.5-ft. Rowland concave grating with 20,000 lines per inch, suggested the undertaking of this work.

ARC SPECTRA

Apparatus and methods.—The mounting, adjustment, and theory of the grating have been described by Professor Ames.¹ The source of light used for the arc spectra consisted of an arc produced by 110

¹ *Phil. Mag.*, 27, 369, 1889.

volts and 11 amperes between carbon terminals, the positive being loaded with the substance under examination. The steadiest and most satisfactory arc was obtained by using equal parts of the metal and carbon dust with the upper pole positive. The arc-stand was rigidly fixed in position at a distance of 125 cm from the slit and in line with the slit and the grating. The light was focused on the slit by a movable quartz lens supported by a tube which was rigidly fixed in line with the slit and the grating.

The iron arc for comparison was a 3-ampere arc such as has been described by Pfund.¹ The terminals were placed in the same stand used for the arc of the other substance.

By means of a shutter with a horizontal slot of the same width as the thickness of the shutter and on a horizontal axis, the spectrum of the substance was taken on the center of the plate and the comparison spectrum on the outer portions.

As mechanical shifts were found on many of the plates several methods of correctly determining the true relative positions of the lines of the two spectra were used. By taking plates of an arc between a positive pole of the substance and a negative pole of iron, the true relative positions of the lines could be determined. When the impurities common to the two arcs were sufficiently strong, the mechanical shift was at once apparent. Another, and more satisfactory, method was to load the positive carbon pole with the substance, iron-filings, and carbon dust, intimately mixed in the ratio 1:1:2. In many cases all three methods were used. The last scheme makes it unnecessary to use the iron arc for comparison, besides obviating mechanical shifts. To test whether the iron lines obtained by using the mixture suffered any displacement because of the presence of the other substances, exposures were made giving the arc of the mixture on the center of the plate and the standard iron arc on either side. The coincidence of the ends of the lines showed that no displacement had occurred.

SPARK SPECTRA

Apparatus and method.—The spark used was produced by a 110-volt alternating current of 25 amperes with a frequency of 60 cycles per second. By means of a transformer the voltage was "stepped up"

¹ *Astrophysical Journal*, 27, 296, 1908.

to 1000, which was again "stepped up" to about 20,000 by another transformer. This potential was sufficient to produce a spark of about 2 cm in length. The spark terminals were of conical-shaped metal, which was reshaped for each exposure in order to keep the spark steady.

In a circuit shunting the spark were condensers consisting of copper foil and glass surrounded by moisture-free transformer oil and having a capacity of 0.03 micro-farad.

The spark used was about 8 mm in length, and its image on the slit was about 7 mm. The capacity that gave the best sparking results when no self-induction was introduced was 0.016 micro-farad, which amount remained constant throughout the work on the wave-lengths of the spark lines.

The comparison arc consisted of loaded carbon poles as described above. The terminals of both arc and spark were fixed in exactly similar sliding clamp-rods, having but one degree of freedom, which were inserted in the same sockets of the fixed arc-stand. Marks on the rods insured the same positions of arc and spark relative to the slit. Moreover, as the focusing lens remained in position after one exposure any difference in the positions of the two sources was at once detected by the displacement of the image on the slit. Though care was taken to have the positions the same, tests, which will be discussed later, proved that great caution was unnecessary.

To avoid mechanical shifts as far as possible, the shutter of the camera-box was detached and fastened to clamp-stands resting on the floor, and the plate-holder was wedged. As in the case of the arc spectra the shift could be detected by comparing the lines in the two spectra due to impurities. But to avoid any possibility of error due to a mechanical shift the method of half-exposure was used, i. e., the plate was exposed half-time to the spark, full time to the arc, and then half-time again to the spark.

The exposures were made in the second-order spectrum, in which $1 \text{ \AA. U.}$ is approximately equal to 1 mm on the plate. Seed's "Gilt Edge" No. 27, Cramer's "Isochromatic," and Wratten and Wainwright's "Panchromatic" plates were used. As the Gilt Edge plates are not sensitive above $\lambda 5100$, the only screens necessary were plate glass and picric acid.

MEASUREMENTS

Method.—In calculating the wave-lengths, the standard iron arc lines as determined by Buisson and Fabry¹ were used. The measurements were made with the dividing-engine constructed by Rowland especially for this work and by the method described by Humphreys.² After reducing the scale of the engine to Ångström units by multiplying by a number slightly different from unity, corrections were made from a calibration-curve for each plate, which was drawn with the standard wave-lengths as abscissae and the differences between these wave-lengths and the readings of the same lines as ordinates. The corrections for each line could then be read from the curve.

As a check on the work the plates were taken so as to overlap.

In estimating the intensities, the iron arc line λ 4045.969 was used as the standard, and its intensity is marked 10, the same as that assigned by Kayser.

Symbols.— n indicates that the line is ill-defined or nebulous; n^r that it is nebulous on the less refracted side; n^b that it is nebulous on the more refracted side; and r that it is often reversed.

¹ *Comptes Rendus*, 144, 1155, 1907; *Journal de Physique* (4), 7, 169, 1908; *Astrophysical Journal*, 28, 169, 1908.

² *Astrophysical Journal*, 6, 180, 1897.

TABLE I
TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
2802.465	8	7	3056.736	5	4
05.680	5	5	58.075	8	7
06.407	2	7	59.731	8	7
09.150	4	3	60.452	2	1
10.276	4	8n ^r	63.484	3	2
12.063	3	3	66.197	8	7
17.838	3	8n ^r	66.357	6	5
20.249	3	5	66.515	5	4
25.377	3	3	71.229	5	5
28.150	3	7n ^r	72.099	8	7
32.158	8	10	72.971	10	8
41.914	8	10	75.220	10	8n
51.087	5	8	78.638	10	8n
53.922	4	7	80.172	3	1
58.399	3	6	84.812	2	1
61.291	3	4	88.026	10	8n
62.213	6	8	89.394	6	6n
68.732	4	7	90.127	5	1
77.418	7	8	97.176	8	7
84.099	8	8n ^r	3101.511	2	2
86.036	3	3	03.800	7	6
87.456	2	6	05.080	7	5
88.923	5	7	06.225	5	6
91.050	5	7	06.800	5	1
2905.649	4	4	07.453	4	1
09.912	4	3	09.576	2	1
12.072	7	6	10.674	7	4
23.484	3	2	11.278	2	1
24.005	2	4	12.050	4	3
28.320	8	6	12.478	5	1
33.526	8	4	14.092	6	
37.301	8	4	17.454	3	
41.993	10	9n ^r	17.663	5	6
46.784	10	9n ^r	18.130	4	
48.247	8	7	19.745	9	7
56.130	8	6	21.595	3	1
56.796	10	4	23.074	7	1
65.681	10	5	23.764	6	1
67.220	10	4	28.640	3	1
68.231	4	3	29.069	3	1
70.376	6	3	30.790	8	7
70.552	6	3	35.926	2	
74.926	4	3	41.513	6	1
83.293	8	4	41.673	5	1
3000.866	7	7	43.750	6	5
02.727	6	6	44.718	3	1
17.175	8	10n ^r	47.258	2	
29.723	4	10	48.030	8	8
42.542	3	1	52.239	8	7
43.847	3	3	53.591	3	
46.671	7	7	54.184	8	7
48.766	4	3	55.654	8	6n ^r

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3157.390	4	2	3251.890	10	8
61.190	8	8	52.849	10	10
61.760	8	8	54.232	10	9
62.557	8	8 ⁿ _r	60.256	2	2
68.519	9	8 ⁿ _r	61.587	10	18
70.923	2	1	63.676	2	3
72.721	3	1	70.562	1	1
79.284	3		71.631	8	8
83.970	4	1	72.064	8	8
86.454	8	5	75.283	2	3
90.868	7	7 ⁿ	76.759	5	4
92.003	8	4	78.276	8	9
95.707	4	3	78.908	8	9
97.508	4	3	79.976	3	4
99.908	8	6	82.320	7	8
3201.586	3	1	87.642	7	10
02.524	6	6 ⁿ	88.125	3	1
03.420	4	2	88.418	2	2
03.815	6	1	88.578	3	4
04.866	4	1	92.059	8	4
05.845	4	1	94.889	2	1
06.340	4	1	99.455	4	3
06.820	4	1	3302.093	2	2
07.328	4	1	06.872	4	1
07.896	4	1	08.382	4	1
09.021	4	1	08.794	6	7
13.136	6	2	09.715	3	2
14.227	8	1	12.679	3	1
14.756	8	2	14.403	6	3
17.042	9	9 ⁿ	15.320	4	8
17.946	3	1	18.006	9	9
18.253	6	8 ⁿ	18.351	2	1
19.208	3	1	21.576	3	3
21.374	3	1	21.700	4	4
22.823	10	8 ⁿ	22.934	10	10
24.227	3	7 ⁿ	26.757	8	8
26.114	5	1	29.450	10	10
26.757	4	3	32.101	8	8
28.586	8	8	35.188	10	10
29.181	8	7	37.892	3	3
29.404	8	7	40.333	8	8
31.299	6	3	41.869	10	9
32.263	7	7	42.137	5	3
34.517	10 ⁿ	12 ⁿ	42.700	2	1
36.102	6	7	43.757	8	6
36.568	9	10	46.724	9	6
38.203	2	1	48.821	8	7
39.030	9	8	49.022	8	7
39.646	8	7	49.408	10	8
41.970	10	12	52.059	3	3
48.600	8	9	52.919	4	1
49.368	2	3	54.642	9	5

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3358.263	8	3	3481.683	1	
58.467	2	1	85.686	2	1
61.218	10 ⁿ	10	89.735	5	4
61.821	5	1	91.047	9	7
62.099	2	1	93.270	4	1
66.171	5	4	95.734	4	1
67.874	2	1	99.098	5	1
69.196	3	3	3500.333	4	2
70.423	8	5	04.887	10	15
71.442	10	5	06.646	3	1
72.197	7	4	07.433	2	1
72.804	10	10	10.840	8	15
74.340	3	3	16.842	2	1
79.200	7	8	20.246	8	9
80.279	8	10	25.241	2	
82.300	6	2	30.578	2	
83.759	10 ⁿ ^r	10 ⁿ	35.395	8	10
85.934	8	5	37.472	2	1
87.830	9	8	47.011	5	1
88.747	3	4	66.095	3	2
90.668	3	1	73.716	5	4
92.199	3	2	74.241	2	1
94.567	9	10	85.861	3	1
98.620	2	1	87.132	2	4
3402.416	4	4	96.046	7	7
03.358	4	1	98.710	6	1
05.085	4	1	3604.295	2	1
07.196	5	4	06.057	1	
09.801	5	3	07.122	2	
11.670	2		12.253	1	
15.985	3		13.749	2	
16.954	3	2	14.195	3	
28.953	2	1	16.957	2	
39.300	2	1	19.453	2	1
43.639	2	2	22.998	4	1
44.326	9 ⁿ ^r	8 ⁿ ^r	24.843	5	7
52.480	3	5	26.087	2	1
55.392	2		26.923	1	1
56.395	5	5	35.198	3	1
56.657	3	1	35.469	8 ⁿ ^r	7
57.490	2		37.965	3	1
59.430	2	1	41.327	4	7
61.506	10 ⁿ ^r	9 ⁿ ^r	42.680	10	9
63.230	2	1	44.461	2	1
65.640	3	4	44.692	2	1
67.268	4	1	46.191	3	2
76.450	1	1	53.493	8 ⁿ	8
76.986	3	1	54.577	4	2
77.184	8	9	58.140	6	4
78.921	4	1	59.748	5	7
80.533	7	2	60.619	5	2
80.891	2	1	62.222	5	5

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3668.950	5	2	3836.511	2	I
71.662	5	2	41.747	3	I
79.680	2	2	75.286	4	2
85.185	10n	15	84.035	2	I
85.949	3	2	88.029	2	I
89.892	5	2	89.956	3	I
94.429	4	I	93.635	I	I
96.882	2		95.238	5	2
98.174	3	I	97.315	2	2
3700.047	3	I	97.578	2	2
01.527	I		98.489	5	2
02.286	4	I	3900.531	7	10
02.976	2		00.957	5	2
04.285	4	2	04.769	8	5
06.215	4	5	11.182	3	2
07.525	2	I	12.575	2	I
08.645	2	I	13.452	8	10
09.951	4	I	14.328	7	3
15.329	2		14.720	3	I
17.391	5	3	15.875	2	2
19.931	3	2	19.815	3	I
21.636	4	5	21.418	5	2
25.119	4	2	24.515	8	4
29.767	8n ^r	5	26.322	4	2
33.782	2	I	27.330	2	I
38.901	3	I	29.865	6	3
41.060	6	4	32.017	3	3
41.140	5	8	34.230	3	3
52.867	8	5	47.754	8	3
53.632	5	3	48.664	10	4
57.683	3	5	56.280	10	5
59.296	10	15	58.208	10	5
61.325	9	12	62.861	7	2
62.326	3	3	64.267	7	3
66.461	2	I	81.766	8	5
69.758	2	I	82.540	5	3
71.642	4	3	84.331	I	I
74.633	2	I	87.756	I	I
82.139	2	I	89.767	10	5
86.025	4	4	92.657	2	I
86.274	2	I	94.696	2	I
3801.065	2	2	98.645	10	6
05.134	2	I	99.466	2	I
05.478	2	I	4002.495	3	I
11.333	5	I	05.979	3	I
13.392	3	3	07.212	I	I
14.860	3	3	08.073	3	I
18.215	3	2	09.137	7	3
21.740	4	2	09.677	4	2
28.174	2	I	12.403	4	3
29.410	3	2	12.813	I	I
36.103	4	2	13.600	4	2

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
4015.398	4	2	4150.549	1	2
16.304	2	2	50.967	4	3
16.988	1	1	58.055	2	1
17.781	4	1	63.653	4	10n ^r
24.572	8	3	69.330	2	1
25.130	3	2	71.023	2	
26.545	5	2	71.910	2	8n ^r
27.614	2	1	73.797	3	3
28.352	4	4	74.471	1	2
30.527	4	2	80.864	3	1
31.773	2	1	83.287	2	1
32.600	1	1	86.118	4	3
33.922	2	1	88.685	1	1
34.918	2	1	4200.786	2	2
35.841	3	1	03.786	4	2
38.322	1	1	11.723	2	1
40.326	2	1	15.520	2	1
43.768	1	1	24.784	2	1
49.392	2	1	27.641	2	1
52.948	1	1	37.883	4	4
53.835	3	4	45.513	2	1
55.021	4	2	49.126	3	1
57.640	3	2	51.604	2	1
58.154	4	4	51.756	1	1
60.269	4	3	56.039	4	2
64.215	4	2	58.531	3	1
65.106	4	2	61.611	3	1
68.140	1	1	63.142	5	5
68.995	1	1	65.712	2	1
70.212	1	1	66.205	2	1
71.476	1	2	70.145	2	1
77.153	2	1	72.445	4	3
78.471	6	4	73.309	2	1
79.730	3	1	74.600	5	5
82.458	4	3	76.443	4	3
99.167	3	1	76.658	2	4
4100.936	2	1	78.135	3	3
02.716	1	1	78.815	3	1
12.726	4	3	80.080	2	1
21.648	2	1	80.343	2	1
22.167	3	2	81.650	4	3
23.308	2	1	82.715	5	3
23.381	3	1	84.990	4	5
27.544	4	3	86.012	8	6
27.968	1	1	87.412	8	6
29.172	2	2	88.181	3	4
31.257	2	1	89.080	6	5
37.290	4	2	89.922	3	6
42.493	2	1	90.228	2	9n ^r
43.044	3	1	90.936	4	4
43.280	2	1	91.136	4	3
48.486	1	1	94.102	6	8

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
4295.755	5	6	4416.535	4	2
98.666	3	6	17.278	5	4
99.140	4	4	17.712	4	5
99.641	5	4	21.467	2	1
4300.047	4	9	21.753	4	3
00.555	4	5	22.822	4	3
01.082	4	6	24.399	2	1
01.934	4	5	25.831	1	1
05.907	4	10	26.053	4	3
07.885	3	10	27.102	5	6
09.088	1	1	30.034	4	1
10.361	1	1	30.307	3	3
11.648	2	2	31.282	3	3
12.875	4	8	32.601	3	2
14.341	3	6	33.581	2	3
14.800	3	6	33.993	5	4
18.635	5	3	36.592	4	3
20.949	3	2	38.233	2	2
21.659	4	2	40.343	4	4
23.435	2	1	41.273	3	3
25.130	5	3	43.201	3	1
26.351	4	3	43.801	4	1
26.983	2	3	44.262	5	12
34.856	3	1	49.127	6	9
37.915	7	8	49.991	2	1
38.498	2	1	50.493	4	6
40.062	1	1	50.902	6	6
41.391	3	3	53.323	6	6
44.314	3	4	53.697	5	5
46.127	4	2	55.324	9	6
46.598	3	1	57.427	9	8
54.080	3	1	62.084	2	1
55.323	2	1	63.387	3	3
60.510	4	2	63.552	3	3
61.151	1	1	64.465	3	4
68.974	2	1	65.803	6	5
69.698	5	3	68.493	6	12
72.403	3	2	70.876	2	4
75.435	1	1	71.235	5	5
88.085	2	2	74.856	4	3
93.927	5	4	79.700	5	3
95.037	10	12	80.607	4	2
95.860	3	3	81.267	6	6
99.772	4	6	82.693	5	3
4400.599	2	1	88.315	3	7
04.273	5	4	89.096	6	5
05.606	2	1	92.557	2	1
07.667	3	1	95.018	4	1
08.109	2	1	96.150	5	4
08.393	3	1	97.747	2	1
12.437	2	1	4501.271	6	11
15.574	1	1	03.777	3	1

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
4506.358	2	I	4667.589	9	8
08.044	I	I	75.125	4	3
08.280	I	I	81.914	8	8
11.176	3	2	90.810	3	I
12.736	8	8	91.341	5	5
18.026	8	8	93.682	3	2
18.691	4	3	96.047	3	I
22.303	8	8	98.790	5	5
27.315	6	7	4710.194	5	4
33.246	9	9	15.312	3	I
33.968	4	9n ^r	22.621	4	2
34.777	9	8	23.179	4	2
35.575	4	8	31.178	4	2
35.923	6	6	33.436	3	2
36.001	5	6	34.684	2	I
37.232	2	2	42.126	2	I
40.870	I	I	42.801	5	5
44.700	8	8	47.694	2	2
48.772	8	8	58.134	8	8
49.635	8	15	58.919	2	2
52.563	8	8	59.283	7	8
55.104	2	I	66.331	2	2
55.498	7	8	69.784	2	2
58.122	2	I	78.271	3	3
59.937	4	I	81.726	3	2
62.630	3		92.499	4	3
63.436	2	2	96.223	3	2
63.765	4	8	97.994	2	2
64.229	I		99.817	4	4
70.911	3	3	4805.109	3	7
71.981	8	15	05.434	4	4
75.526	2	I	08.536	3	3
85.839	2	3	11.087	2	2
89.962	4	4	12.248	3	2
99.232	4	2	19.043	I	2
4609.375	3	2	20.420	4	4
14.292	I	I	27.597	I	2
17.268	9	11	36.128	2	2
19.532	2	I	40.878	5	5
23.098	6	8	43.990	I	2
29.335	6	6	48.460	3	3
34.878	2	2	56.013	5	6
35.548	2	I	68.286	4	4
37.875	2	2	70.141	6	6
39.361	4	4	80.918	I	I
39.665	4	4	82.342	I	2
39.945	4	4	85.093	6	8
45.188	4	3	93.003	I	I
50.017	4	3	93.433	I	I
55.704	2	2	99.925	6	7
56.060	3	2	4911.188	I	3
56.474	7	6	13.625	4	6

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
4915.241	2	2	5206.089	2	2
19.879	1	3	10.394	6	8
21.785	3	3	19.720	2	6
25.422	2	2	22.683	2	4
26.170	1	2	23.636	2	2
28.357	3	3	24.323	4	8
37.746	1	1	24.960	4	6
38.306	3	2	26.555	2	2
41.583	1	1	27.187	2	2
48.214	1	1	38.575	2	4
64.750	2	2	46.740	2	4
68.491	2	2	46.811	2	2
73.055	2	4	52.107	2	4
75.358	3	2	55.824	2	4
77.748	3	4	59.985	2	4
78.209	3	2	63.316	2	2
81.746	10	11	63.504	2	2
89.161	3	3	65.968	4	8
91.077	9	10	66.281	2	2
97.100	2	2	81.928	2	4
99.512	9	9	82.376	2	6
5001.011	3	3	83.448	4	8
07.218	8	8	84.380	2	4
09.650	3	3	89.100	2	2
13.302	4	4	89.278	2	2
14.262	8	7	89.731	2	2
16.174	4	7	94.754	2	2
20.045	5	7	95.783	4	3
22.872	4	6	97.293	4	7
24.853	4	5	98.423	4	6
25.580	4	6	99.828	2	3
35.916	4	6	5335.348	2	2
36.474	4	6	51.094	4	5
38.412	4	5	69.653	4	6
39.962	4	5	90.004	2	3
40.627	2	2	90.259	2	3
43.590	2	3	5409.625	4	6
45.430	2	2	26.268	2	4
52.880	2	4	29.155	3	6
62.115	2	4	36.651	2	2
64.659	5	7	38.327	2	4
66.007	2	3	46.671	2	4
71.490	2	2	49.187	2	3
87.069	2	2	53.672	2	4
5113.441	4	6	60.614	6	5
20.429	4	6	71.188	4	4
45.470	4	4	74.284	4	7
47.476	4	4	77.732	4	5
52.184	4	5	81.450	4	6
73.744	6	8	81.898	6	6
88.696	2	7	88.236	5	5
92.978	6	8	90.157	6	6

TABLE I—Continued

TITANIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
5503.885	6	6	5780.838	4	4
11.798	4	3	86.039	8	5
12.538	6	8	5804.388	3 ⁿ	4
14.364	6	8	23.764	3	4
14.541	6	8	66.508	7	9
65.507	5	5	80.334	2	4
5644.180	5	7	99.338	6	6
48.638	5	4	5918.600	3	3
62.211	5	8	22.160	4	4
75.474	6	8	53.205	5	8
89.513	7	7	65.862	7	8
5702.727	6	4	78.582	6	8
11.944	6	4	99.003	4	4
15.168	5	4	6064.659	7	6
16.517	5	3	85.247	6	5
20.516	4	3	91.188	7	6
39.532	4	5	6126.239	7	7
40.035	4	3	6215.280	6	6
56.924	3	4	58.110	9	10
62.340	6	4	58.708	9	10
66.413	6	5	61.096	10	10
74.101	6	5			

TABLE II

MANGANESE

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
2812.845	3	3	2889.622	1	3
13.488	3	1	92.408	2	4
13.997	2	1	92.672	2	1
14.935	2	3	97.810	2	
15.618	2	1	98.006	2	
17.198	2	1	2900.565	1	4
17.986	3	1	02.212	2	
18.790	3		07.236	3	1
18.844	1		08.004	1	1
21.571	2	1	08.886	1	1
22.561	3	1	14.618	9	2
28.806	2	1	20.480	1	1
30.807	3	2	23.728	1	1
36.328	2	1	24.450	1	1
58.670	2		25.597	8	2
72.594	2	1	28.699	3	1
79.480	1	4	30.163	2	
82.916	1	1	33.068	7	8
86.688	1	4	34.024	3	1
89.550	2	6	35.663	2	1

TABLE II—Continued

MANGANESE

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
2939.314	7	8	3189.957	1	1
40.330	2	1	99.927	2	1
40.512	6	1	3201.121	2	1
41.047	3	1	02.530	2	1
41.094	1	1	03.736	2	1
41.755	1	1	06.864	3	1
44.410	1	1	12.862	5	3
49.224	8	9	16.928	3	2
53.031	1	1	23.228	2	1
63.615	2	1	24.745	4	2
78.582	2	1	26.015	3	2
3002.492	1	1	28.071	7	5
07.657	2	1	30.700	5	4
11.171	2	1	36.762	6	6
11.378	2	1	37.372	6	2
16.462	3	1	40.373	4	2
22.754	3	1	40.604	4	2
40.601	3	2	43.778	5	4
41.231	2	1	48.508	4	4
43.146	2	2	51.117	4	3
43.348	3	2	52.937	5	4
43.773	3	1	56.140	5	5
44.592	6	3	58.410	4	4
45.589	3	2	60.212	4	3
45.815	2	1	64.692	4	4
47.040	3	2	67.794	3	3
54.389	6	2	68.703	3	2
62.131	5	2	70.347	3	2
66.034	5	2	73.010	3	2
70.306	5	2	78.544	3	2
73.149	5	2	80.640	1	1
79.642	5	2	80.744	5	1
81.331	4	2	90.979	2	1
97.052	4	2	95.836	2	1
3110.686	3	2	96.027	2	1
13.037	1	1	96.872	3	2
13.808	2	1	98.220	3	3
15.473	3	2	3300.956	2	
20.342	2	1	03.277	3	2
22.886	1	1	04.898	2	2
25.023	1	1	07.008	3	1
26.858	1	1	08.785	3	1
32.296	2	1	11.906	3	2
32.805	2	1	13.199	3	2
36.960	2	1	13.514	3	2
42.674	3	1	14.419	2	1
48.188	5	2	14.898	3	2
58.731	1	1	16.328	3	2
59.946	2	1	16.452	1	1
61.053	5	2	17.304	4	2
77.953	1	1	20.603	4	2
78.495	6	3	30.666	4	1

TABLE II—Continued
MANGANESE

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3343.729	3	2	3693.668	4	4
45.354	3	1	96.588	4	3
51.605	2	1	3700.302	1	1
54.652	1		01.733	3	2
66.226	2	2	06.074	4	4
3407.982	1	1	18.926	4	3
19.801	1	1	31.925	3	3
33.570	3	2	46.613	3	2
38.978	3	3	50.758	2	1
41.998	5	10 ^r	56.631	2	1
50.614	2	2	63.376	2	2
60.330	5 ^r	10 ^r	67.686	2	1
74.064	4	8	68.261	3	1
74.136	4	8	98.262	2	
82.924	4	10 ^r	99.256	2	2
88.678	4	10 ^r	3800.551	2	2
95.845	5	8	01.909	2	2
97.526	3	8	06.709	3	1
3524.548		8	06.860	7	8
31.839	4	8	09.119	2	2
32.002	5	8	09.591	5	4
32.128	5	8	10.687	2	2
47.790	5	10	16.738	2	3
48.025	4	8	23.510	4	5
48.187	4	8	23.882	4	4
52.737	2	1	24.772	3	2
69.485	5	8	32.435	3	2
69.796	8	8	33.836	6	5
70.061	4	6	34.361	6	6
74.085	1		36.508	4	1
77.865	7	6	38.329	4	2
79.656	2	1	39.776	4	4
80.120	1		41.721	4	5
83.692	2	1	43.979	3	4
86.536	5	5	52.493	3	2
89.980	1		53.487	3	3
95.109	5	4	56.663	3	3
3601.279	1	1	64.107	3	2
07.530	6	6	72.046	3	2
08.532	6	6	72.956	3	2
10.298	6	6	73.373	3	1
19.407	6	5	89.448	3	3
23.794	5	4	96.347	2	2
29.740	4	3	98.362	3	3
60.405	3	3	3904.318	1	2
69.839	1	1	04.960	2	1
70.518	3	1	11.130	3	1
76.950	3	2	11.424	2	2
80.147	1	1	16.628	2	1
82.091	2	2	18.312	3	2
84.866	1	1	21.766	3	1
91.815	1		22.682	3	1

TABLE II—Continued

MANGANESE

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3923.339	2	2	4070.265	3	3
24.070	3	2	75.251	2	1
26.470	4	3	79.204	7	4
29.252	3	2	79.430	7	4
29.654	3	2	82.922	8	6
36.757	2	2	83.620	8	6
42.974	2	1	89.932	3	1
52.844	2	2	92.348	2	1
75.883	2	2	95.040	1	
77.081	2	2	95.245	2	1
80.156	1	1	102.970	2	1
80.883	1	1	93.460	1	1
82.170	1	1	93.550	3	1
82.572	2	2	95.370	3	1
82.903	1	1	97.880	2	1
84.177	2	1	10.917	6	2
85.238	3	2	13.260	3	1
87.097	3	2	14.408	2	1
87.460	3	2	22.250	2	1
88.677	1	1	22.770	2	1
91.602	1	1	23.296	1	1
92.488	2	1	23.548	1	1
4001.190	1	1	31.130	6	3
93.259	2	1	31.560	1	1
98.030	2	1	34.618	2	1
11.534	2	1	35.033	4	2
18.093	8	6	37.275	3	
20.083	3	1	41.060	3	2
26.226	3	2	47.530	3	1
28.601	2	1	48.794	3	2
31.797	18 n^r	7	55.497	2	1
33.057	18 n^r	5	57.003	3	1
34.477	18 n^r	5	76.594	4	3
35.724	5	5	89.992	4	3
37.556	3	1	4201.780	3	2
41.343	12	6	11.750	3	2
45.208	4	3	20.613	3	1
48.734	11	5	35.125	6	4
49.012	2	2	35.306	6	4
49.445	2	1	39.723	6	3
51.726	2	1	57.653	5	3
52.461	2	2	61.298	3	1
55.205	2	2	65.920	5	3
55.545	10	4	78.682	2	1
57.948	4	2	81.097	5	3
58.917	5	4	84.084	5	2
59.375	4	2	4300.203	2	1
61.741	5	2	12.546	4	1
63.553	7	3	23.403	1	1
65.049	3	2	74.939	3	2
66.221	2	1	81.701	3	2
67.998	3	1	82.639	3	1

TABLE II—Continued

MANGANESE

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
4408.084	2	I	4826.901	2	I
11.875	3	2	38.240	2	I
14.880	6	4	44.312	3	I
19.774	3	2	54.613	I	I
36.051	2	I	54.805	I	I
36.351	5	4	62.052	I	
47.160	4 ⁿ	4	4965.976	3	I
51.584	6	5	74.349	I	
52.535	2	I	85.777	2	I
53.015	4	3	5004.910	3	I
55.012	5	3	10.366	2	I
55.320	5	3	29.818	I	I
55.820	5	3	30.643	I	I
57.051	5	2	74.806	2	I
57.555	5	4	86.775	I	
58.268	5	4	5117.944	3	
60.389	4	2	49.255	I	
61.090	6	4	50.937	2	I
62.037	7 ⁿ	6	96.603	5	3
64.680	6	4	97.228	2	
70.138	6	4	5255.330	6	3
72.800	6	4	60.774	3	I
79.400	3	2	98.033	2	I
90.071	5	3	5341.068	8	5
91.645	3	2	77.623	7	4
96.647	3	I	88.526	6	4
98.898	6	5	94.679	7	3
4502.218	6	5	99.494	6	4
03.872	3	2	5407.429	6	3
23.407	2	I	13.690	4	2
42.451	3	I	20.371	6	6
44.427	2	I	32.553	4	2
48.589	3	I	70.644	7	4
4605.378	5	3	81.401	6	2
26.552	5	3	5505.874	3	5
71.694	4	I	16.774	6	4
4701.150	3	I	37.753	4	3
09.708	7	4	51.991	3	3
27.476	7	4	73.016	I	2
39.004	6	3	73.688	2	2
54.046	10 ⁿ ^r	6	5738.287	6	2
61.521	6	4	80.168	6	2
62.375	8	6	5816.837	5	2
65.852	6	4	48.951	4	2
66.414	6	4	6013.480	10	10
83.454	10 ⁿ ^r	6	16.631	10	10
4823.521	10 ⁿ ^r	6	21.794	10	10
25.600	2	I			

TABLE III

VANADIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3126.224	9		3237.879	3	
30.281	9		39.045	3	
33.336	9		41.177	2	
34.944	4		41.988	3	
36.527	3		43.287	2	
41.500	2		49.574	3	
42.488	4		50.776	3	
45.354	4		51.889	3	
45.979	3		52.911	3	
47.275	2		54.768	4	
55.405	2		55.653	3	
62.568	2		59.542	3	
64.740	3		61.086	3	
68.136	3		62.075	3	
83.407	15		63.239	7	
83.984	15		65.904	3	
85.402	15		66.090	3	
87.700	7		67.690	13	
88.079	2		71.129	12	
88.503	5		71.636	2	
89.078	2		73.025	3	
90.674	8		76.130	15	
93.917	4		77.946	3	
96.503	3		79.845	4	
98.098	10		82.533	3	
3200.005	4		83.310	5	
01.227	2		84.364	3	
02.376	10		89.388	3	
04.190	3		91.680	3	
05.268	3		98.148	5	
05.575	6		98.738	4	
07.404	7		99.089	3	
08.351	4		3308.258	2	
10.104	3		09.184	4	
10.433	2		19.024	3	
12.396	7		20.147	3	
14.751	4		21.551	3	
15.380	3		21.691	3	
17.119	4		24.395	3	
18.872	2		27.996	2	
26.109	3		28.407	2	
27.125	2		29.858	8	
27.418	3		33.573	2	
29.612	3		56.358		
30.647	3		63.553	3	
31.952	3		65.558	8	
33.191	3		66.897	3	
33.550	2		71.126	3	
33.866	2		74.048	2	
34.519	3		76.063	4	
36.580	3		77.393	4	

TABLE III—Continued

VANADIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3377.627	4		3528.205	2	
83.758	4		29.729	4	
84.608	3		30.765	5	
85.949	3		33.666	2	
87.390	2		33.743	6	
90.388	3		34.739	2	
90.773	3		38.236	3	
96.528	2		40.535	2	
97.585	3		42.657	2	
97.845	3		43.495	4	
3400.401	6		45.188	4	
01.349	3		45.343	4	
02.572	6		48.922	2	
03.366	3		51.506	2	
04.970	2		53.263	4	
05.160	4		55.147	2	
06.851	4		55.739	2	
08.010	3		56.241	3	
09.101	3		56.800	5	
14.203	3		57.165	2	
17.076	3		60.578	3	
18.534	4		62.156	2	
23.874	3		63.395	2	
25.075	4		66.275	4	
42.017	3		68.939	3	
42.330	3		71.042	3	
45.819	3		71.657	3	
54.900	3		73.518	3	
56.930	3		74.776	2	
57.157	3		75.135	2	
63.415	2		77.877	2	
79.843	3		80.826	2	
82.188	2		83.702	2	
85.931	5		89.752	3	
89.477	4		92.014	3	
93.165	4		92.534	2	
96.942	4		93.332	3	
97.038	3		3600.040	2	
98.203	2		05.585	1	
99.837	2		16.740	1	
3500.825	2		35.482	2	
03.199	2		39.045	1	
04.425	5		41.108	1	
05.687	4		43.881	1	
06.847	3		44.736	2	
12.024	2		45.626	1	
17.289	8		47.359	1	
19.165	3		48.995	2	
20.022	4		52.453	1	
22.565	3		56.728	2	
24.714	4		63.599	3	
25.767	3		65.151	2	

TABLE III—Continued

VANADIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3667.737	3		3772.154	1	
71.210	3		74.111	1	
72.414	2		75.720	1	
73.411	3		76.160	1	
75.705	4		78.680	4	
76.693	3		79.650	1	
80.119	3		81.409	2	
81.287	1		82.553	1	
83.123	4		84.671	1	
86.268	3		87.553	2	
86.703	1		90.326	3	
88.073	6		90.484	2	
90.277	6		93.619	2	
92.225	6		94.955	4	
94.627	1		96.473	1	
95.347	4		99.900	4	
95.866	5		3803.474	5	
98.027	1		03.786	2	
99.484	1		03.914	2	
3703.585	7		06.805	1	
04.703	5		07.507	2	
05.044	5		08.523	4	
05.580	1		09.609	3	
06.045	1		13.494	5	
08.728	2		15.533	3	
15.467	3		17.854	1	
19.017	1		18.246	4	
22.004	1		19.978	4	
22.201	1		21.490	3	
27.350	2		22.014	2	
29.047	1		22.902	3	
32.756	2		23.229	3	
34.426	2		23.985	2	
37.999	1		28.193	2	
38.762	2		28.572	4	
41.513	2		29.627	2	
45.807	2		31.041	2	
47.138	1		32.433	2	
47.992	2		33.816	2	
50.875	2		35.183	2	
51.783	2		36.065	2	
52.868	2		36.524	3	
53.288	2		37.630	1	
55.714	1		37.858	2	
56.043	1		38.998	2	
58.555	1		39.388	2	
59.319	2		40.148	1	
60.803	1		40.436	3	
61.444	1		40.751	1	
63.148	2		41.901	2	
69.079	2		43.001	2	
70.541	1		43.496	1	

TABLE III—Continued

VANADIUM

WAVE-LENGTHS	INTENSITIES		WAVE-LENGTHS	INTENSITIES	
	Arc	Spark		Arc	Spark
3844.446	2		3899.139	1	
44.896	2		3900.180	2	
45.018	2		01.244	2	
45.451	2		02.253	5	
52.408	2		03.260	2	
55.367	6		04.215	2	
55.839	7		06.746	3	
56.670	2		08.317	1	
58.691	2		10.791	2	
59.926	2		12.202	3	
60.637	2		12.883	2	
62.237	2		14.329	2	
62.497	1		16.415	1	
63.399	1		20.497	2	
63.877	1		21.906	3	
64.857	4		22.429	4	
67.642	3		24.659	4	
71.091	2		25.246	4	
72.747	1		27.932	3	
75.897	5		30.020	4	
76.096	4		31.347	3	
85.785	1		34.026	3	
86.590	2		35.143	2	
90.188	5		36.288	2	
91.859	3		38.216	2	
94.049	2		39.339	2	
96.159	2		42.008	3	
97.081	2		43.666	3	
98.281	2				

II. EFFECT OF CAPACITY AND SELF-INDUCTION ON THE WAVE-LENGTHS OF THE SPARK LINES

In view of the work of Exner and Haschek,¹ Haschek,² Kent,³ Eder and Valenta,⁴ Kayser,⁵ Middlekauff,⁶ Cooper,⁷ and others on spark spectra, tests were made for the possible effect on the wave-lengths of the spark lines in consequence of varying the capacity and self-induction in the secondary circuit.

¹ *Sitz. der Kais.-Akad. der Wiss. in Wien*, 1897.

² *Astrophysical Journal*, **14**, 181, 1901.

³ *Ibid.*, **17**, 286, 1903.

⁴ *Ibid.*, **19**, 251, 1904.

⁵ *Handbuch der Spectroscopie*, **2**, 297, 308-310.

⁶ *Astrophysical Journal*, **21**, 116, 1905.

⁷ *Ibid.*, **29**, 329, 1909.

APPARATUS AND METHODS

The apparatus used was the same as that already described, with the addition of self-induction in series in the spark circuit. This self-induction was produced by three coils of No. 10 copper wire, each 1 meter long and having 106, 206, and 186 turns respectively. The first and second were 8 cm in diameter and the third 15 cm. The second was mounted within the third and the whole was so arranged that the self-induction could be varied within the limits, 0.00007–0.0012 henry, without stopping the spark.

In determining the wave-lengths of the spark lines given in the tables, the capacity in the circuit was 0.016 micro-farad, but no self-induction was used. Throughout the spectra there was no evidence of a shift of the spark lines if the center of gravity of the lines is considered, but many lines become asymmetrical.

As several observers have announced detections of shift under varying conditions, rigorous methods were applied in the present work. In the beginning a test was made to see if any shift was produced by not having the arc and the spark in the same position. The arc was kept in its usual position, and, with the circuit conditions constant, the spark was displaced relatively. With the focusing lens fixed, plates were taken when the spark terminals were placed six or seven inches farther from the slit than the arc, when it was displaced perpendicularly to the line of the grating and the slit as far as the illumination of the grating permitted, and also when it was changed from place to place while the spark was running. No test gave the slightest evidence of a shift. In the last case a shift would have affected the definition of the lines, but they remained perfectly sharp.

Though these results showed that it was unnecessary to be especially cautious in regard to having the arc and the spark in exactly the same position, the precaution was taken in all of this work.

The titanium and the manganese sparks were subjected to varying conditions of capacity between the limits 0.0005–0.03 micro-farad, and of self-induction between the limits 0.00007–0.0012 henry. Special attention was given to those titanium lines in the region near λ 3900 which have been specially investigated by Kent. Not only were the spark spectra taken successively with the various combinations of capacity and self-induction, but also with variations of both

without stopping the spark or changing the plate. In the latter case a shift of the sharp lines would have caused blurring, which, however, was not observed. In order to detect mechanical shifts the method of half-time exposure was used.

GENERAL EFFECTS

The general effect of the increase of current from 10 amperes to 35 amperes was to intensify the lines and diminish the time of exposure. No reversals were found.

Self-induction eliminated the air lines, lengthened the time of exposure, caused the enhanced lines to revert to unenhanced lines, changed the characteristics of the spark spectra to those of the arc, and caused broad lines to become asymmetrical and nebulous, generally toward the blue end of the spectrum. Many lines sharp when only capacity was used showed the same effect when self-induction was introduced.

Increase of capacity shortened the time of exposure, broadened many lines, and made the enhanced lines asymmetrical and nebulous, generally toward the red end of the spectrum. Large capacity caused a few lines to reverse.

SHIFT OF LINES

The titanium lines, which, according to some observers, show a large displacement, are lines that are either enhanced or are broad in the arc spectrum, and this fact seems to be the cause of the disagreement among investigators as to whether a true shift occurs. Kayser points out the difficulties of determining a true shift in regard to broad and asymmetrical lines. A true shift should mean a shift of the center of gravity rather than the shift of the maximum point of intensity; but as there is at present no way of accurately determining the true center of gravity owing to the variations of the area of the lines, due to the time of exposure and of development, the center of maximum intensity is assumed to be the center of gravity.

So far as the writer has been able to discover, all calculations of shifts have been based on the position of the maximum intensity, which was found to vary slightly under different conditions of capacity and self-induction in the case of broad lines. Two of the titanium lines, λ 3900.53 and λ 3913.45, observed by Kent, are enhanced, and

the other two, λ 3904.77 and λ 3998.64, are broad and asymmetrical in the arc spectrum and also in the spark if self-induction is used. All are subject to asymmetrical broadening under changes of capacity and self-induction. Accordingly in the present work there arose the difficulty of determining not only the true center of gravity but also the real point of maximum intensity of these lines.

Since this work was done, Janicki¹ has investigated the shift of spectral lines, and he thinks that the apparent shift of the titanium lines found by Kent, and later by Kent and Avery,² is due to the asymmetry of the reversals.

CONCLUSION

The conclusion drawn from the evidence furnished by this investigation is that no determinable shift between arc and spark lines, or between spark lines subjected to different circuit conditions has been found.

My thanks are due Professor Ames, under whose supervision the work was conducted, Mr. L. E. Jewell, for his advice and assistance, and Dr. Anderson and Dr. Pfund, for their suggestions.

¹ *Annalen der Physik* (4), **29**, 866, 1909.

² *Astrophysical Journal*, **27**, 70, 1908.

BIOGRAPHY

Clinton Maury Kilby was born on November 1, 1874, in Suffolk, Va. His early training was received in the public schools and in Suffolk Military Academy. In 1892 he entered Randolph-Macon College, Va., and in 1896 received the A.M. degree. During the two years immediately preceding graduation, he was instructor in mathematics. He held the position of principal of Public High Schools for two years, and during the years 1898-1905 was teacher of physics and mathematics in Woodberry Forest School, Va. During the summer of 1903 he studied physics and mathematics at the University of Chicago, and during the summer of 1904, physics and mechanical drawing at Columbia University. In 1905, he entered Johns Hopkins University as a graduate student in physics, taking physical chemistry and mathematics as subordinate subjects. For three years he held a Virginia scholarship, and in 1908-1909 was lecture assistant to Professor Ames.

